Integrated Cryogenic Propulsion Test Article and Thermal Vacuum Hotfire Test Results Overview

JANNAF In-Space Propulsion TIM

JSC Propulsion

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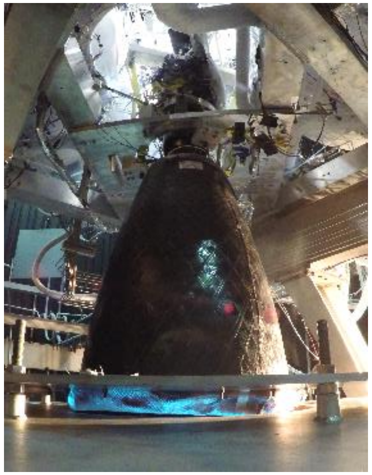
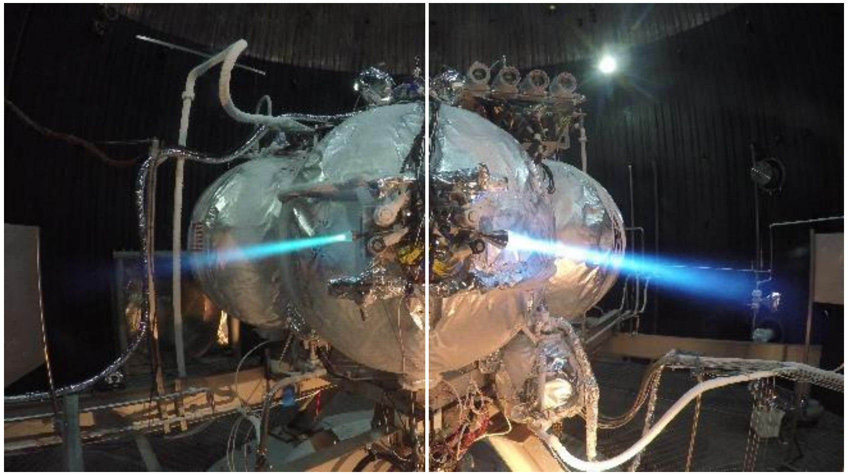
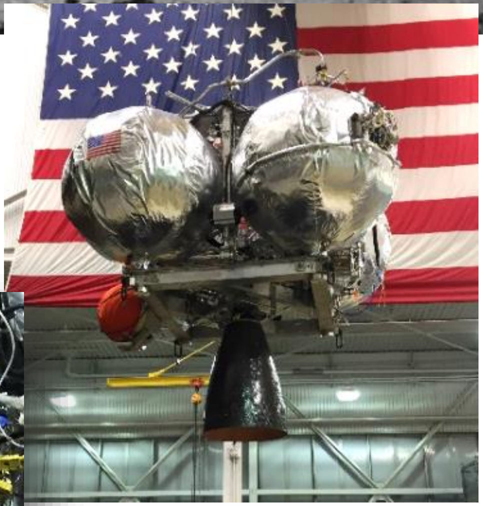
Integrated Cryogenic Propulsion Test Article (ICPTA)

- LOX/Methane spacecraft prototype
  - Built at JSC in 2016 for this thermal vacuum environment
  - New components and hardware from the former Morpheus vehicle and other projects
  - Integrated into Plum Brook ISPF in Dec/Jan
  - First Hotfire test at ISPF: Feb 3, 2017
- 6 Weeks of testing at ISPF
  - Dozens of RCS, ME, ME+RCS, loading, chill, thermal tests
  - Ambient temp / deep thermal, High altitude / vacuum
  - Joint operations: PB operated environment and prop loading, JSC operated vehicle
- JSC, KSC, GRC, SSC team focused on LOX/Methane research and other experiments

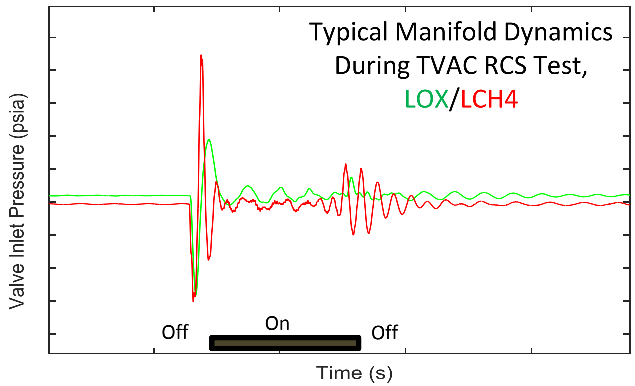
ICPTA Design Overview

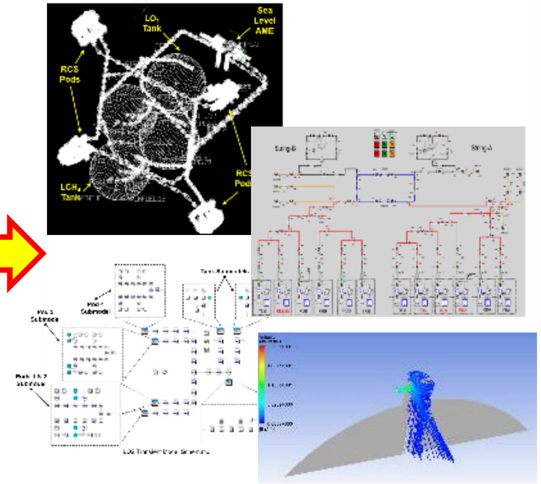


- Lander configuration (tested w/o legs), central main engine, pod-mounted reaction control engines on vehicle perimeter
- 4x 48” spherical tanks (2ea. LOX / Methane) insulated with MLI + aerogel
- Common plumbing for main and RCS engines, insulated with MLI + aerogel
- RCS engines: Two pods (7lbf + 28lbf in each)
  - Coil-on-Plug ignition, 85:1 nozzles
  - Gas/Gas, Gas/Liquid, Liquid/Liquid operation; 100msec → SS ops
- Main Engine
  - 2,800 lbf Vac, 5:1 throttling, thrust measurement system
  - Coil-on-plug (COP) ignition, O2/CH4 igniter, 100:1 composite ablative nozzle
- Helium Pressurization
  - COPV with vac rated foam + MLI, LN2 cooling systems
  - High pressure HEX on ME Nozzle, warm gas reg panel, flowmeters, diffusers in prop tanks
- Flight computer external to test cell w/50-ft harness
- 320+ static/dynamic sensors on vehicle: temp, press, accel, load, strain, mics, etc
- Piezoelectric Mass Propellant Gauging (MPG) system
- CFM Experiments: Internal Tank Chill, facility/vehicle cryo loading heat transfer
- 4 load cell interface for vehicle to structure: real-time weight
- Multiple heaters on vehicle and around test cell
- Fluids: 4800 lbm LOX, 1800 lbm Methane, 7lb helium
- Checkout hotfire test at JSC in Dec, 2016

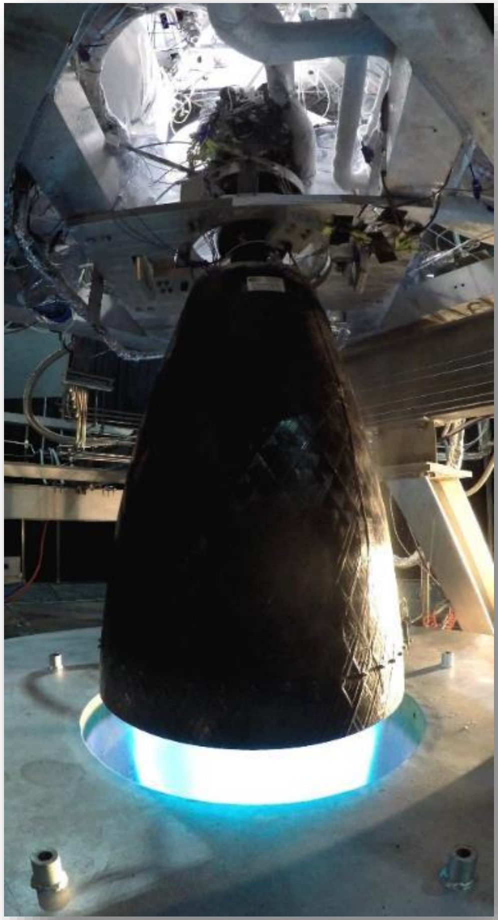
Test Objectives Overview

- Provide ME and RCS thrust for Plum Brook facility characterization
- Collect LOX/Methane vehicle model validation data for a variety of experiments
  - System-level model verification: RCS manifold transient fluids, ME+RCS dynamics, vehicle thermal, cold helium pressurization / ullage collapse
  - Subsystem model verification: RCEs/ME performance, Tank/Line insulation, Modal propellant mass gauging, Methane heat transfer, Tank chill, internal tank chill system
- Subsystem demonstration: coil-on-plug ignition, facility nozzle diffuser (w/blowback), others
- **Analysis and model results will be reported at the 2017 AIAA JPC**





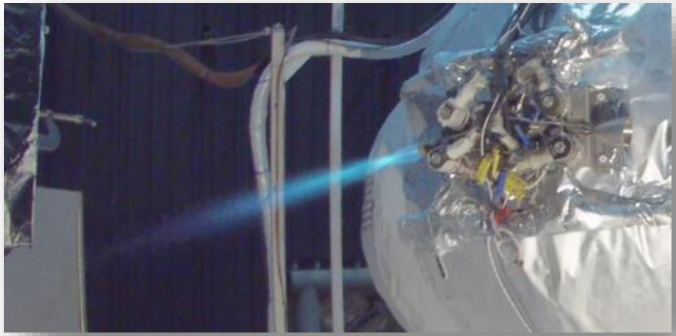
Numerous math models: fluids, thermal, SS/transient



Plum Brook Test Campaign Results

- **Accomplishments for test campaign, LOX/Methane research, and tech development:**
  - Multiple main engine tests up to 55 sec duration, sufficient to characterize the Plum Brook facility
  - 800+ Reaction Control Engine ignitions: numerous system operational modes including self-priming
    - Vehicle RCS hotfires at thermal vacuum conditions (First) with thermal-related no-lights observed
  - Modal Propellant Mass Gauging performance data collected during hotfire and propellant loading/draining (First)
  - Cryo Fluid Management: Line/Tank chill heat transfer data collected for liquid methane (First) and liquid oxygen/nitrogen; demonstrated vehicle methane tank spray cooling system (First)
  - Coil-on-Plug ignition system tested at vehicle level in high corona risk range (First)
  - Cold Helium Pressurization of a cryo propellant at flight-like conditions
  - Numerous other minor experiments

ICPTA Combo hotfire test, 2/28/17



TVAC Hotfire of 7lbf Jet
3/9/17

Backup

Modal Propellant Gauge (MPG) System

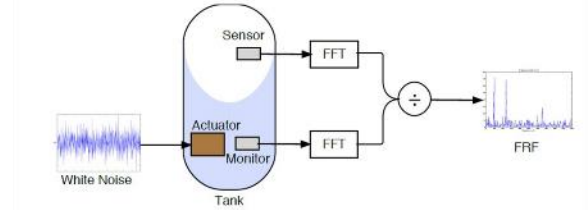
- Orion Mass gauging experiment for Orion and AES
  - KSC conducting under MOA with Orion and AES
- Propellant mass measurements
  - Non-intrusive sensor bonded to outside of a propellant tank that measures the mass inside
  - Capable of zero-g and 1 g mass measurement
    - Zero-g flights of small tank have shown good results
  - Open question of system performance under engine vibration
- Test Objective
  - Gather data during hot-fire at sea level and altitude conditions to understand engine vibration/acoustic effects on measurements
  - Measure any differential draining that occurs
    - Installed on two LO2 tanks (not methane)
  - Gather data during loading/unloading to gauge 0-99% fill levels
- Test Plan
  - Install PZT sensors on two LOX tanks and vehicle structure
  - Perform modal tap checks of installed system
  - Collect data during sea level hotfires at JSC and altitude hotfires at Plum Brook with and without actuator powered
    - Main Engine and RCS only operation desired

Modal Propellant Gauge – How does it work

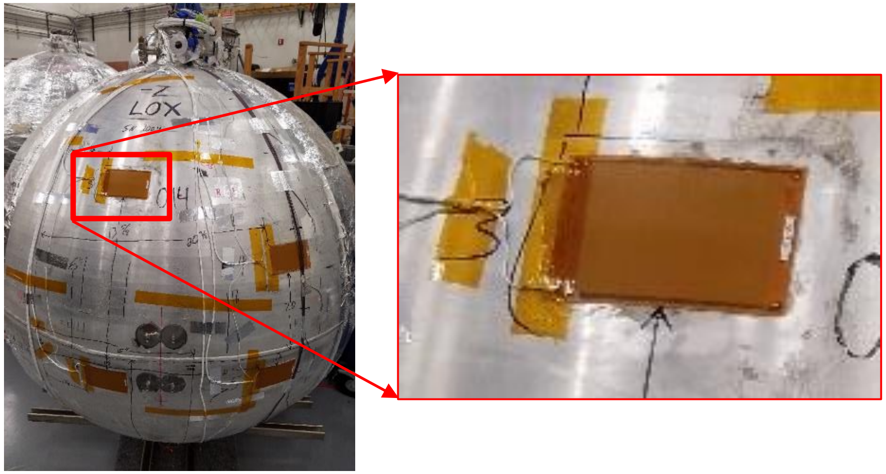
Rudy Werlink/KSC

NASA (**Lead Zirconate Titanate**)* PZT modal active vibration technology for non-invasive fluid mass measurement

- Experiment concept. A PZT patch actuator is adhered to an experimental tank partially filled with water. Broadband white noise is introduced to the tank through the actuator. The Frequency Response Function is computed from the FFTs derived from the sensor and monitor signals.



(PZT refers to the type of Piezoelectric sensor/actuator $Pb[Zr_xTi_{1-x}]O_3$, I also use the abbreviation loosely to Refer to the active vibration system)



-Z LOX Tank with PZT patch sensors/actuator